VACUUM EFFECTS ON SOLID-PROPELLANT ROCKET FUEL

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In this paper I will briefly review a Langley Research Center program on the effects of vacuum on solid-propellant rocket fuel. This program includes measurement of outgassing rates for rocket fuels in vacuum, identification of the outgassed products, measurement of the changes in mechanical properties during vacuum storage, and measurement of the effects of vacuum storage on the ignitibility of the fuel. We are looking at fuels which are likely candidates for future space missions which includes fuels being considered for hybrid motors. To date in this program outgassing rates have been measured and the outgassed products identified for two fuels; Polyurethane and PBAA.

The outgassing rates were measured using the "Rate of Rise" technique in which the rate of pressure rise caused by the propellant sample in a known volume is measured.

Figure 1 shows the measured outgassing rate for Polyurethane as a function of exposure time. The exposure time ran to about 500 hours or 21 days. The outgassing rate is given in torr-liters per square centimeter per second. The outgassing rate decreases rather rapidly for the first 100 hours and then continues to decrease at a much lower rate for the remainder of the test. It is still decreasing after 21 days in vacuum. During this exposure period the outgassing rate decreased from about 3×10^{-7} torr-liters per square centimeter per second to about 3×10^{-8} torr-liters per square centimeter per second, i.e., about a factor of 10. These outgassing rates of around 10^{-7} torr-liters per square centimeter per second are about what would be expected from rubbery materials like this. There is some scatter in the measured rates which results from variations in the outgassing processes and is not inherent in the measuring technique.

Figure 2 shows the same variation but this time for the PBAA fuel. Again there seems to be a change in rate around 100 hours but the rate of decrease after 100 hours is much greater than for the Polyurethane. This increased rate coupled with the fact that the initial outgassing rate for the PBAA was somewhat higher resulted in a factor of 100 decrease in outgassing rate during the exposure as opposed to a factor of 10 for Polyurethane.

To get an idea of what pressure level might be experienced in a rocket motor in space, the measured outgassing rates were used to calculate the pressure-time profiles for several motors. Figure 3 presents the results for a 35-inch spherical motor with Polyurethane fuel. The conventional equation was used for the calculation and it is shown in figure 3. The pressure in the motor is "P" at any time "t." The pressure in the motor is "P_o" at $t = o$, "Q" is the outgassing rate of the propellant per unit area, "A" is the surface area of the propellant exposed, "F" is the nozzle conductance, and "V" is the volume inside the motor occupied by the gas. Using the measured outgassing rates for Polyurethane the calculated pressure in this motor, without a nozzle closure, ranges from about 3×10^{-6} torr to about 3×10^{-7} torr after about 21 days. This pressure level is typical for many of the motors we examined.

As noted previously the outgassed products were identified. A time-of-flight mass spectrometer was installed in the chamber with the propellant sample. The time-of-flight mass spectrometer is briefly described in the paper "Comparison of Partial Pressure Analyzers" which is presented elsewhere in this volume. Figure 4 shows the experimental setup used for the identification of the outgassed products. A slab of propellant is suspended in the chamber on a thermocouple. The flight tube is mounted through the rear port of the chamber and the ionization or sampling portion is in the vicinity of the propellant sample. Using this setup the gases evolving from the fuel were identified as a function of storage time in vacuum.

Figure 5 shows a mass spectrogram of Polyurethane after 160 hours in vacuum. The mass-to-change ratio is shown on the abscissa and the peak height in amperes is shown on the ordinate. The 18 and 17 peaks, which are coming from water, are by far the largest peaks in the spectrogram. Many of the other peaks present indicate that there are some hydrocarbons evolving from the Polyurethane but they have not been identified as yet. The ratio of m/e 28, nitrogen, and m/e 32, oxygen, indicates that some air is also evolving from the Polyurethane. It was noted that this spectrogram was taken after 160 hours in vacuum. The spectrograms taken at the other times show that water was always the main outgassing constituent and accounted for about 60 percent of the total pressure throughout the entire exposure period.

Figure 6 shows a mass spectrogram for the PBAA after 180 hours in vacuum. In this case water is certainly not the main constituent evolving from the fuel. The main m/e peaks coming from the PBAA are hydrocarbons. Most of the peaks that are seen here are probably coming from the cracking pattern of some parent hydrocarbon that we have not yet identified. It is interesting to note that many of the peaks shown in this figure, and in the mass spectrogram for Polyurethane, can be accounted for if they had the chemical formula $C_XH_{2X\pm1}$ with X ranging from 2 to 8. One likely parent peak for the PBAA is the peak at m/e of 126. A comparison of four hydrocarbons with mass number 126 shows cracking patterns very similar to the pattern shown here but none of them matched well enough to identify the hydrocarbons evolving from the PBAA.

These data are being presented in more detail at the 21st Interagency Solid Propulsion Meeting in San Francisco on June 9, 10, and 11, 1965. Further analysis of these data is taking place along with some additional work to aid in the identification of the outgassed products. Tests to measure the effects of vacuum on the mechanical properties of the fuel are scheduled for later this year.

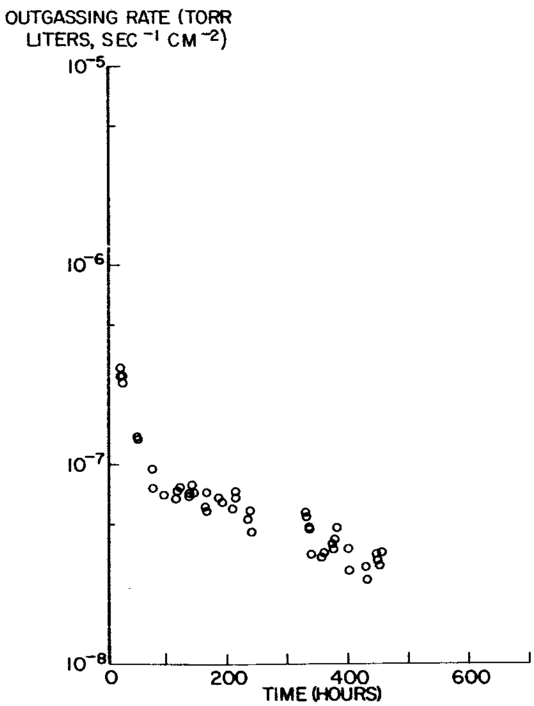

Figure 1.- Variation of the outgassing rate of polyurethane with time of exposure to vacuum.

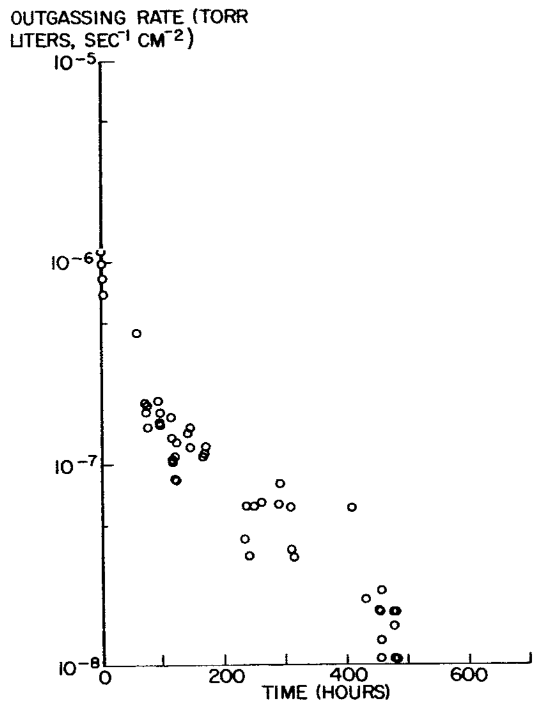

Figure 2.- Variation of the outgassing rate of PBAA with time of exposure to vacuum.

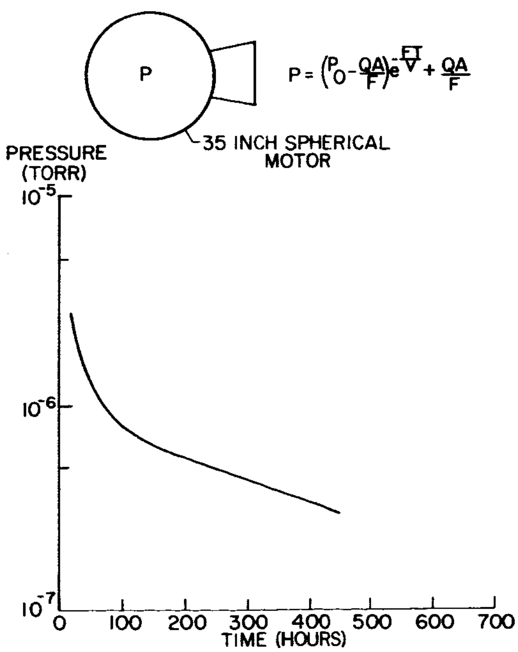

Figure 3.- Variation of pressure inside 35 inch spherical rocket motor with time of exposure to vacuum.

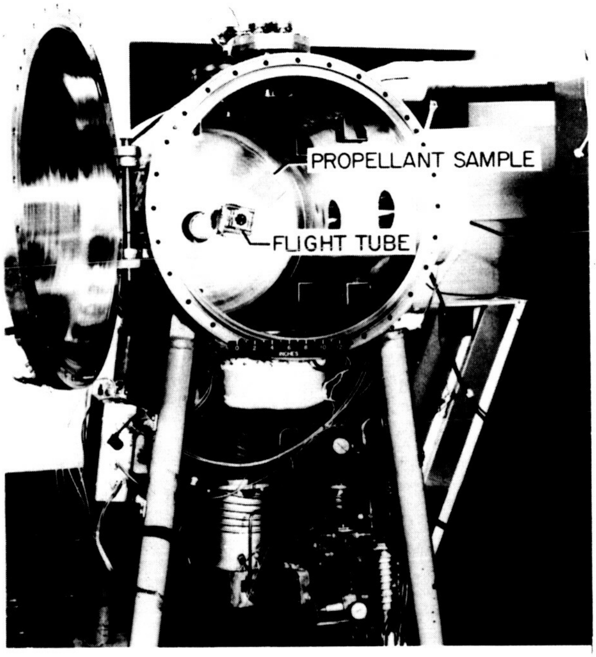

Figure 4.- Experimental Set-Up.

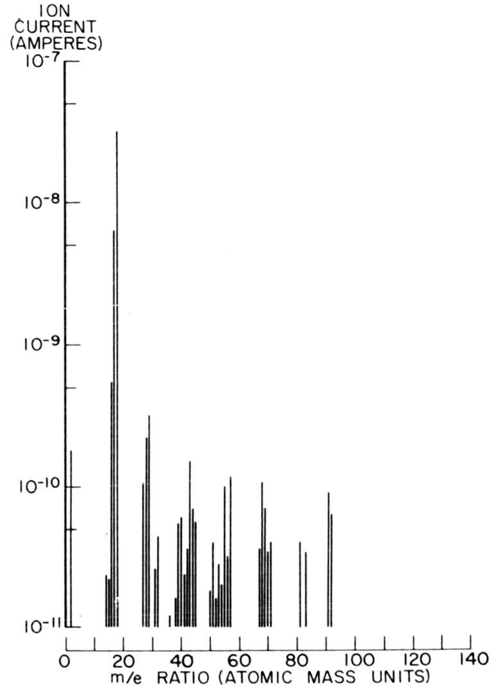

Figure 5.- Mass spectrogram of outgassing products from polyurethane.

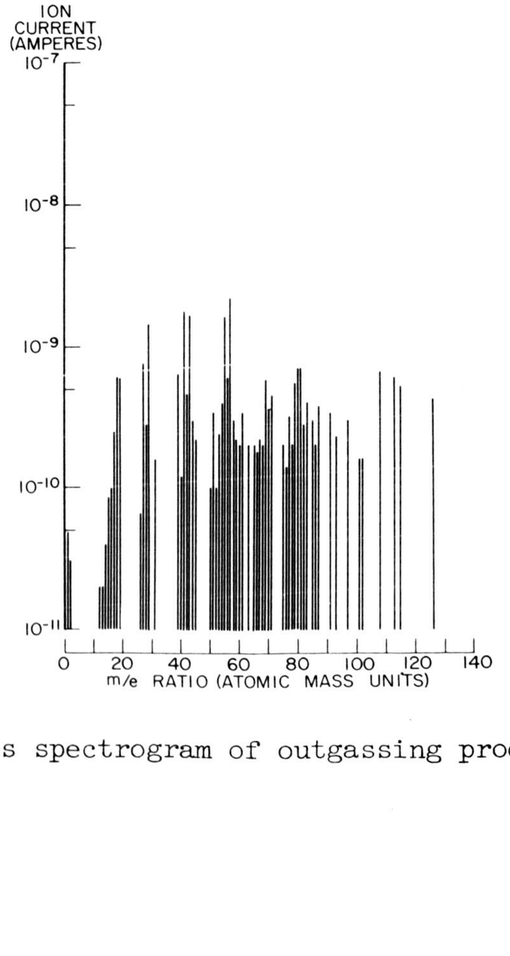

Figure 6.- Mass spectrogram of outgassing products from PBAA.